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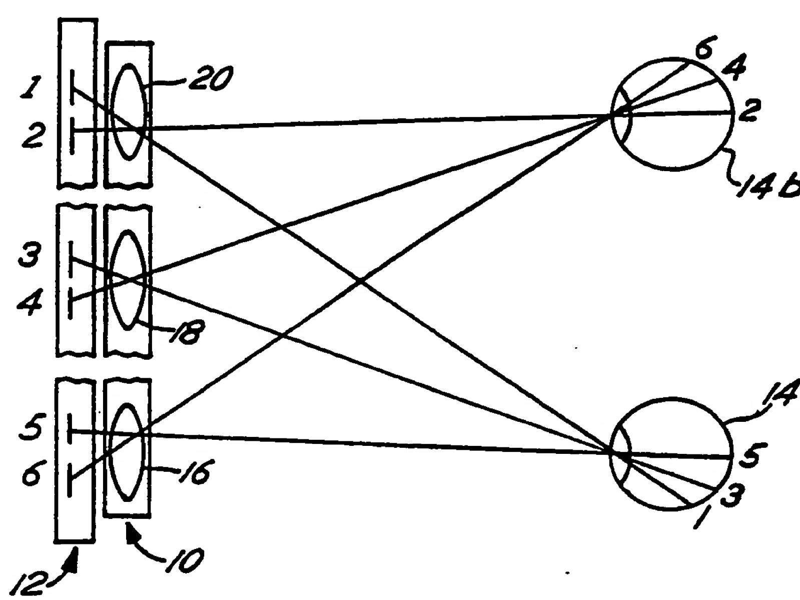

(57) Abstract

An apparatus f r three-dimensional display of a two-dimensional image generated from a single view such as that produced on a television screen or a photograph. The apparatus comprises a two-dimensional array of lens assemblies which are placed adjacent to the plane of the two-dimensional image. The lens assemblies comprise, in the preferred embodiment, an object lens, an image lens, and a semi-rigid transparent layer between the lenses. The apparatus can be modified t provide three-dimensional viewing of a projected image such as that produced by a slide or movie projector by adding a specularly mirrored surface to the object lens and placing the apparatus at distance where the screen would normally be. Several methods of manufacturing the apparatus are disclosed.

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THREE-DIMENSIONAL IMAGE DISPLAY METHOD AND APPARATUS

BACKGROUND OF THE INVENTION

This is a continuation-in-part of Serial No. 07/618,363 filed November 23, 1990.

1. **Field of the Invention**

This invention relates to three-dimensional image display systems. More particularly, this invention relates to a new three-dimensional image display system that is adaptable to any image producing source, whether television, print, movie screen, computer monitor, or other source.

2. **Description of Related Art**

Attempts have been made since at least the 1940's to produce a satisfactory, universal three-dimensional image display system. The essential problem to be solved is the production of two independent images to the right and left eyes of an observer, which are combined in the brain to give the viewer a perception of depth.

The attempts at stereoscopic three-dimensional image display have involved a wide variety of techniques, in a variety of media, with limited results. Additionally, the techniques known in the art typically involve some sort of complexity or hindrance, either singly or in combination. Such encumbrances have included cumbersome or expensive decoding glasses to be worn by the viewer, sophisticated and costly signal multiplexing, polarization or color filters, multivibrators, oscillators, multiple camera image generation and phase adjustment devices, and special strips, screens and filming techniques. Moreover, many three-dimensional image display systems known heretofore produce a three-dimensional image observable in a narrowly circumscribed location. Additionally, three-dimensional image display techniques have heretofore been primarily directed to motion pictures, either in television or film projection. Consequently many image sources that contain 3-D information have never been used for 3-D viewing.

Three-dimensional image display has a vast number of potential applications, if it can be produced simply, without the aid of mechanical or electrical contraptions, and in a variety of media. Home entertainment, theater entertainment, medicine (e.g., x-ray analysis, surgery, diagnostic imaging), scientific research (e.g., computer modelling, cosmology) and advertising, are just

a few of the possibilities. Unfortunately, the limitations in the state of the art up to now has curtailed application of three-dimensional image display to places of amusement, leaving its wider applications in the home, the work place and the research laboratory largely untouched.

The Yano patent, U.S. Patent No. 4,078,854, discloses a stereo image projection system in which multiple pictures of an object photographed with a fixed parallax are projected onto a lenticular screen. The screen focuses the pictures on a diffusion plate which is then decoded by another lenticular screen and a large lens. Stereoscopic vision is effected by the parallax effect of both eyes when the viewer is in a localized viewing area. In the Bonnet patent, U.S. Patent No. 4,621,897, a stationary lens is used to produce a magnified image at a plane located at a predetermined distance away from the stationary image. A lenticular grating encodes the image and another grating and ocular lens decodes the image. An immobile observer looking through the gratings perceives a stereoscopic image, while a mobile observer will have the impression of "turning" around the object. Both the Yano and the Bonnet patents involve lenses and lenticular screens, however, they both use a secondary conversion step in forming a stereo image, and they operate on quite different optical principles and do not suggest or teach the present invention.

The present invention overcomes and supersedes prior limitations in the art through the discovery of a method for three-dimensional image display adaptable to virtually any two-dimensional image that already contains three-dimensional information. Ordinary two-dimensional images such as those produced on television sets, postcards, photographs, and even computer screens, are typically obtained from a single perspective or view, for example, from the view of a single camera lens. However, these two-dimensional images apparently already contain as an incident to their generation three-dimensional image information. The information can be retrieved and displayed through the application of a conversion means lens assembly to the image such that adjacent pairs of picture elements are perceived by the right and left eyes independently. By the application of a conversion means lens assembly of the present invention, stereoscopic, three-dimensional display can be achieved simply, at relatively low cost, and for virtually any two-dimensional image source that has three-dimensional information incidental to its image generation. The invention requires no filters, glasses, multiplexing, polarization, signal processing, or other

electrical or mechanical device or procedure. Moreover, the conversion means lens assembly can be mass produced at low cost by currently available manufacturing technology.

Without prejudice to the scope of the appended claims, the applicant herein below sets forth what is believed to be the principle of operation of the invention, the summary of what applicant believes to be his invention, and a detailed description of how to make and use the invention as the applicant understands it.

SUMMARY OF THE INVENTION

An apparatus is provided for the three-dimensional display of a two-dimensional image comprised of a multiplicity of adjacent image elements generated from a single view, comprising an optical system adjacent the object plane of the two-dimensional image for separating adjacent image elements for independent viewing by the right and left eyes. The optical system, in the preferred embodiment, comprises a two-dimensional array of miniature lens assemblies.

The parameters of the optical system will vary depending on the application. The optical system's purpose is to take adjacent picture element of the two-dimensional object and separate them to interpupillary distance so that one picture element is perceived by the left eye and the other is perceived by the right eye. The optical system incorporates lens assemblies arranged in a two-dimensional array placed adjacent to the object plane to accomplish this objective. Without the lens assembly, groups of pairs of adjacent picture elements appear as a single element to the eyes, and the scene will be viewed as a two-dimensional image. When the optical system is used, individual picture elements are separated to the right and left eyes, and the scene is viewed as a three-dimensional scene. The conversion means is designed so that separation is accomplished without appreciable distortion, overlapping of images, or noticeable aberration.

The theory which the applicant understands the invention to be founded on is that with a 2-D image generated by an ordinary camera, the scene is perceived by a multiplicity of perspectives, the number being greater as the focal depth increases and the subject matter depth increases. The multiplicity of perspectives is contained within a multiplicity of closely spaced points, which, if separated by the optical system according to the present invention causing adjacent closely spaced object plane elements to be perceived by right and left eyes independently, gives the viewer a perception of depth.

The present invention can also be used in front projection formats, e.g., slides or movies. In this case, the object side of the conversion means lens assembly is specularly mirrored and replaces the existing front projection screens.

The present invention is also usable to create instant 3-D film pictures. A removable transparent normalizing layer is placed between the conversion means lens assembly and the scene being photographed. The light sensitive media, color filters or diffraction grating of the film is placed in proximity of the object lens surface.

BRIEF DESCRIPTION OF THE DRAWINGS

The features, objects and advantages of preferred embodiments and methods of the present invention can be more easily understood by reference to the accompanying figures, in which:

FIG. 1 is a simplified diagram of the optical system of the present invention applied to a generic 2-D object plane;

FIG. 2 is an oblique view of the optical system of FIG. 1 placed adjacent the object plane of a color television set;

FIG. 3 is a cross-sectional view of a preferred construction of a lens element in the array shown in FIG. 1;

FIG. 4 is a front view of a section of the lens array shown in FIG. 3;

FIG. 5 is a cross-sectional view of the optical system of FIG. 1 showing ray traces from the object plane to the viewers eyes, the optical system having lenses with a semi-rigid transparent core;

FIG. 6 is a cross-sectional view similar to FIG. 5 except that the lenses do not have a semi-rigid transparent core;

FIG. 7 is a cross-sectional view of an alternative embodiment in which the array of lens assemblies comprises two overlapping arrays;

FIG. 8 is a cross-sectional view of a conversion means lens array and encoding means as applied to instant film;

FIG. 9 is a cross-sectional view of a conversion means lens array as applied in a front projection application;

FIG. 10 is a diagram of a heated roller method of manufacturing lens arrays.

FIG. 11 is a diagram of a method of manufacturing UV curable plastic lens arrays;

FIG. 12a is an illustration of a cross-sectional view of a laser method of manufacturing lens arrays;

FIG. 12b is a diagram of the wave train for the laser of FIG. 12a;

FIG. 12c is a cross-sectional view of an assembly used in a modified form of the method shown in FIG. 12a;

FIG. 13 is a cross-sectional view of an emulsion coated substrate used to form a mold for lens arrays;

FIG. 14 is a cross-sectional view of the substrate FIG. 13 during exposure of the substrate to a laser;

FIG. 15 is a cross-sectional view of the substrate FIG. 13 after exposure to a laser;

FIG. 16 is a cross-sectional view of photographic molds being used to make a cured plastic lens array;

FIG. 17 is a cross-sectional view of the emulsion and substrate of FIG. 13 shown before and after exposure;

FIG. 18 shows the removal of the backing from the cured lens array of FIG. 16;

FIG. 19 is a cross-sectional view of a completed lens array of FIG. 18 with a portion of mold remaining as a light absorbing buffer ring or mask;

FIG. 20 is an illustration of the object lenslet surface of the lenslet array of FIG. 19;

FIG. 21 is an illustration of image side (toward viewer) of the lenslet array of FIG. 19 with the light absorbing mask;

FIG. 22 is an illustration of a smooth heated roller method of manufacturing lenslet arrays in which photographically produced molds are used to form lenslets and create an optical mask with portions of the molds shown broken away and enlarged;

FIGS. 23 A-D are illustrations of an electrostatic method of manufacturing lenslet arrays;

FIG. 24 illustrates a modified form of the method shown in FIGS. 23 A-D;

FIG. 25 illustrates a xerographic method of forming lenslet arrays on transparent plastic sheets;

FIG. 26 illustrates an ionic electronically adjustable lenslet array according to an alternative embodiment of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT OF THE INVENTION

Referring to FIG. 1, a simplified diagram of the optical system 10 according to present invention is shown applied to a generic object plane 12. FIG. 1 is a horizontal planar cross-sectional view through the plane of the eyes 14a and 14b. The object plane 12 could be the surface of a TV screen, a newspaper photograph, a postcard, or any other planar image surface composed of closely spaced adjacent image elements. In FIG. 1, the object plane 12 is composed of a multitude of adjacent pairs of image elements, of which three pairs have been shown. Placed in front of the image plane is the optical system 10 of the present invention.

The optical system 10 is an array of conversion means lens assemblies. Three such lens assemblies are represented in FIG. 1, each of which, as the applicant understands the invention, separate the adjacent image elements of the object plane to the right and left eyes, as shown. Lens assembly 16 separates elements 5 and 6 such that the right eye 14b sees element 6 and the left eye 14a sees element 5. Similarly, lens assembly 18 separates elements 3 and 4 such that element 3 is seen by the left eye 14a and element 4 is seen by the right eye 14b. Similar separation is performed by lens assembly 20 on image elements 1 and 2. If an entire array of lens assemblies is placed in front of a 2-D object plane, the right and left eyes perceive two different perspective views of the 2-D image and the perception of depth.

For purposes of illustration of a preferred embodiment, FIG. 2 shows an oblique view of a television tube 24 having placed adjacent to it the optical system 10. The optical system 10 comprising a plurality of lens assemblies 26 arranged in an array which covers the TV screen 28. The broken away and enlarged portion 30 of TV screen 28 shows the linear array of red, green and blue phosphor dots 32 that are struck and illuminated by the beams of electrons 34 from the electron gun 27.

FIG. 3 is a cross-sectional view of one lens assembly of FIG. 2, designed for minimum coma, minimum spherical aberration and absorption of ambient light. Each lens assembly 26 is made of an optically clear material with an index of refraction of 1.52. The lens assembly 26 comprises an object lens 36 which

faces the object plane 12, a semi-rigid optically transparent layer 38, and an image lens 40. To minimize tangential coma and spherical aberration, the radii of curvature of object lens 36 and image lens 40 are in a ratio of thirteen to one. For the embodiment for use with a color television, object lens 36 is given a radius of curvature of 0.0234 inches. The distance 42 between the vertices of the object lens and the image lens 40 is 0.00473 inches.

To gain rigidity, the lens assembly 26 can be made with the semi-rigid optically transparent material 38 sandwiched between the object and image lenses 36 and 40. Preferably, the index of refraction of the layer 30 is substantially the same as that of the object and image lenses 36 and 40. The optically dead area of the lens assembly 26 is covered by a light absorbing buffer ring 44. The inner diameter 46 of the buffer ring 44 equals the diameter 48 of the image lens 40, which is one half the diameter 50 of the object lens 36. The buffer ring 44 has a flattened vertex region 52.

It will be appreciated that the lens assembly shown in FIG. 3 is appropriate for large scale object planes 12. However, the construction of FIG. 3 may be modified to permit stereo perception where coherent fiber optic cables are used, as for example in medical endoscopy. In this event, the object lenslets 36 are placed at one end of the fiber optic cable, and the image lenslets are placed at the other end. In this embodiment, the coherent fiber optic cable itself is essentially an elongate substitute for the semi-rigid optically transparent layer 38 in FIG. 3.

Referring now to FIG. 4, the lens assemblies 26 are shown arranged in a two-dimensional array. The image lens 40 is surrounded by the light absorbing buffer ring 44 and light absorbing vertex region 52 filling in the region external to the image lens 40. For the color television embodiment, the diameter 54 of each lens assembly is approximately 0.00751 inches.

FIG. 5 is a horizontal cross-sectional view in the plane of the viewer, with rays traced from the object plane 12 through the optical system 10 to the left and right eyes 14a and 14b. The phosphor dots 32 have an adjacent object element spacing 60, and a horizontal scan distance between like colored phosphor dots is designated by numeral 62.

The surface of television screen 28 (or other optically transparent cover of a conventional CRT) limits the proximity of the optical system 10 to the object plane 12. A plane 64 is selected at distance d from the viewer's eyes

where the rays to the right and left eyes cross-over and do not interrupt the same lens. The distance d is the optimum distance to resolve all object plane detail. At plane 64, the distance between ray 3 to the right eye 14b and ray 4 to the left eye 14a must be equal to the distance d' at plane 66 for unity magnification.

From FIG. 5, it can be seen that red, blue and green rays 2, 4, and 6 are directed to the right eye 14b and red, blue and green rays 1, 3, and 5 are directed to the left eye 14a. Thus, the requirements of stereo separation are met in FIG. 5. Under ideal conditions, the object lens width 50 is equal to the adjacent object element spacing 60. However, depending on the size of the object elements to be resolved and separated to the right and left eyes, the lenses can be chosen to be larger or smaller, or placed at a farther or closer distance to the object plane 12. Generally, smaller lens sizes are desirable for wider fields of view with minimum distortion.

Referring now to FIG. 6, the array of lens assemblies are shown constructed without the semi-rigid optically transparent middle layer. The previous statements regarding radii of curvature, lens diameter and index of refraction of the lens assemblies of FIG. 3 apply here as well. As in FIG. 5, stereo separation of rays 1-6 is accomplished by the lenses 16, 18, and 20.

In FIG. 7, an alternative construction for the optical system is shown in cross-section adjacent to an object plane 12. The optical system comprises a first lens array 100 and a second lens array 102. Each lens element of the first array 100 comprises a double concave lens 104 having radii of curvature of 0.067 inches. Transparent material 111 is air. The second lens array 102 has a layer 106 of semi-rigid transparent material adjacent the lens 108. Lens 108 has a radii of curvature of 0.041 inches. A 0.005 inch separation 110 is provided between the first and second lens arrays. The index of refraction for lenses 104 and 108 is 1.49, and the diameter or width of each lens element 112 is 0.040 inches. Again, the size and spacing of the lenses may vary depending on the size of the image elements to be resolved, the distance to the viewer's eyes, and other factors.

Referring now to FIG. 8, the optical system 10 is shown applied to instant film. The instant film media 120 is applied in proximity to the object lens surface 122 of a conversion lens array 124 which is part of the film pack. A removable normalizing layer 130 making intimate contact with the image lens surface 126 is also included with the film in the film pack. The normalizing

layer 130 is preferably a transparent plastic material, and may be the same material as used to make the lens elements of lens array 124. The silver crystal, dye combination, or diffraction grating 67 is the source of ray 1 directed to the left eye 14a, and ray 2 directed to the right eye 14b, by the conversion lens array 124, thereby producing stereo separation. Normalizing layer 130 makes the image appear on the film as if the conversion lens array 124 were not present. When the film is developed the normalizing layer 130 is removed and the instant 3-D picture is viewable. If 3-D is not desired, the normalizing layer 130 is left intact since it will protect the lenses of the array 124.

FIG. 9 shows the principle of the invention using a front projection conversion lens array. An optical system 200 comprising an array of lens assemblies 202 has a specularly mirrored surface 204 applied to the back of the array. A right image is projected onto the array by projector 210 and a left image is projected by projector 212. Rays from the right projector 210 are directed to right eye 14b by the optical system 200. Likewise, rays from the left projector 212 are directed to left eye 14a. The result is a 3-D image observed by the viewer or viewers.

It is not necessary to have two projectors 210 and 212 for film not originally filmed as independent left right images, nor is it necessary that the number of projectors be limited to one or two. When a single projector is used the rays from the specularly mirrored surface 204 are in the order of the rays from object plane 12 in FIG. 5.

COMPOSITION AND MANUFACTURE OF CONVERSION MEANS LENS ARRAYS

The manufacture of the conversion means lens assembly 10 can be by a variety of methods, the choice depending on the degree of expense one is willing to incur or the degree of accuracy and performance one requires of the optical system. As one possibility, laser light deformation of optical quality translucent plastics with the proper indices of refraction, to form convex lens surfaces of the desired radii of curvature, will provide a superior optical system, but at relatively high initial engineering and production costs.

Referring to FIG. 10, plastic sheeting 300 is given the proper curvatures and shapes by heated metal rolling dies 302 and 304. Two layers of plastic sheeting 300 are formed over a transparent semi-rigid core material 30 and are conformed to the proper shape by the pattern on rolling dies 302 and 304, thus producing the optical system 10 in one operation. With proper choice of materials for the plastic sheeting 300, no mold release is required. This method will produce large volumes of medium to high quality optical systems 10 at low cost per unit.

At the low budget end of the spectrum, see FIG. 11. A vacuum frame 401 and ultraviolet light and infrared heater assembly 403 are used to form the optical systems 10. A sandwich is made of upper and lower plastic film sheets 400 which have UV curable optically clear plastic 402 sandwiched between them. This assembly, along with a rigid lower mold 404 and a thin UV transmitting upper mold 406 are placed in the vacuum frame 401. The transparent cover 408 of the vacuum frame is closed and vacuum is applied to the frame 401, causing the blanket 410 to be forced against cover 408 and thus squeezing the UV curable plastic and thin plastic sheets 400 into the mold indentations in upper and lower molds 406 and 404. The vacuum frame is maintained at a constant temperature by the infrared heater 412. The molding process is observed. When the plastic layer 402 is evenly dispersed, the UV light 414 is turned on, curing the plastic 402.

FIG. 12a illustrates a laser blow molding system to blow mold a multiplicity of miniature lenslets in plastic sheet material 501. A Q switched laser beam 503 is reflected by a heat mirror or X-Y scanning mirror 511. The laser beam 503 is focused by a lens 504, which is a 28 mm RKE telescope

objective lens to form a beam profile 500. An X-Y table 512 moves plastic sheet 501 in a horizontal plane in increments determined by the final lenslet array requirements, for example in 0.0035 inch steps in the X and Y directions. Plastic sheet 501, in a preferred embodiment, is a film known as Roscolene 882, but can be any transparent material that can be heated by the laser used. A Control Laser Model 512 QT used in the Q switched mode was adjusted to form a pulse train shown in FIG. 12b. The laser was pumped at 12.75 amps with a 2 ms dwell Q switched at 4 MHz. The sequence of events of the X-Y table 512 is stopped and mirror 511 is stationary. The laser is turned on by pulse train 508 beginning with pulse 509. Pulse 509 vaporizes some of the plastic material at the focal point of the beam 500 within plastic sheet 501 to form a bubble 502 in the sheet 501. Pulses 510 heat plastic sheet 501 allowing bubble 502 to expand. Surface 513 of plastic sheet 501 is nearest lens 504 and is hotter than surface 514 away from the lens. Surface 513 being hotter expands more easily forming upper lenslet surface 513 with a smaller radius of curvature than lower lenslet surface 514.

The plastic film 501 may be provided with a central layer 513a which is more highly light absorbent. This method forms two element lenslets in an array with inter-lens spacing controlled by the positions at which the X-Y table 512 stops or mirror 511 deflects beam 503. The requirements for constructing a lenslet array for a 4" diagonal LCD TV are that the radius of curvature of surface 513 should be 0.0018" with bubble 502 0.001" in diameter and centered 0.0015" below surface 513. The surface of the bubble 502 is 0.0048" from surface 513. The optimum viewer to screen surface distance is 20" for an array with these parameters.

After the first lens element in the array is formed, laser beam 503 is turned off for duration 507 (FIG. 12b), which is the time required for the X-Y table to reposition the film 501 such that a new lenslet can be formed at position 516. The process of internally vaporizing then melting the film and creating another lenslet repeats itself at position 516. The X-Y table then stops and another pulse train 508 occurs. This process is repeated until the desired array size is formed. Although a YAG Laser is the preferred laser for use in the method shown in FIG. 12a, any Q switched laser of sufficient power at its output wavelength to vaporize and melt an appropriate plastic material can be used. The higher the laser frequency the smaller the lenslets that can be made.

Referring now to FIG. 12c, Arno aluminized window film 520 composed of a film substrate 521 and an aluminized surface 522 together form an assembly. When the aluminum surface 522 is heated it forms lenslets and the aluminum acts as an iris or mask for the lenslet.

Another method of manufacturing the optical system according to the present invention is shown in conjunction with FIGS. 13-19. FIG. 13 shows an emulsion 601 on a substrate 600. The substrate 600 can be any material transparent to the wavelength needed to activate the emulsion. The emulsion thickness determines the maximum moldable lens thickness. The substrate 600 and emulsion 601 in the present example is Autotype Novastar diazo film.

The emulsion 601 is then either directly exposed using a laser beam 500 as shown in FIG. 14, or exposed through a mask 605 placed against substrate 600 (FIG. 17). If the mask technique is used, the mask 605 causes the proper energy density within the emulsion 601 to create a cross-linking of the exposed emulsion to a contour of the desired lenslet surface shape. The exposed emulsion 604 remains in place when the emulsion 601 and substrate 600 are developed as by soaking the substrate 600 and emulsion 601 in warm water for two minutes and then spraying to remove inactivated emulsion 602. The result is a mold which contains the contour of a multiplicity of lenslet surfaces 607, shown in FIG. 15.

The mold shown in FIG. 15 is then air-dried using standard diazo film processing technology. FIG. 16 shows two molds 609 and 610 formed in accordance with the techniques of FIGS. 13-15 and 17. The mask for each of the molds 609, 610 describes a different mold surface containing contours 607 and 608. Referring to FIG. 17 and FIG. 16, the mask 605 is designed in order to make the radius of the curvature 607 of mold 609 one-thirteenth of the radius of curvature 608 of mold 610. This helps to reduce spherical aberration and coma. Aspheric surfaces can also be made by controlling the laser 500 of FIG. 10 or the mask 605 of FIG. 17. It will be appreciated that still other techniques can be used to make the molds 609 and 610. Curable transparent plastic material 611 is placed between the molds 609 and 610. The plastic material 611 could be UV curable. Item 612 is a polished lower mold retainer sufficiently rigid to not bow when the assembly of 609, 610 and 611 is placed in a vacuum frame. The assembly of molds 609, 610 and curable plastic material 611 in FIG. 17 is held in a vacuum frame and the plastic material is cured according to the technique described in conjunction with FIG. 11.

FIG. 18 shows substrate 600 being peeled off plastic material 611 after curing. The cured emulsion 604 adheres to the plastic material 611. FIG. 19 shows the completed lens array after washing the desired amount of cured emulsion away. Almost all cured emulsion 604a is washed from lenslet surface 612. A 0.5% sodium hypochlorite solution (90% water, 10% household bleach) works well as a washing solution. Surface 612 becomes the object lens facing the object plane having the adjacent image elements to be separated for independent viewing by the right and left eyes.

Still referring to FIG. 19, surface 613 remains when cured emulsion 604b is partially washed away using the sodium hypochlorite solution. Surface 613 (viewer side) should have a diameter 614 one-half the diameter 615 of object lens surface 612. Cured emulsion is washed away on surface 613 side until diameter 614 is free of emulsion to a diameter one-half of diameter 615. Thus, cured emulsion 604b width 617 is equal to lens diameter 614.

FIG. 20 shows the object lens 612 side of a lens array 10 with remaining emulsion 604a acting as a mask. FIG. 21 shows the image lens 613 side of lens array 10 (viewer side). The remaining emulsion 604b acts as an optical mask. The lenslet surfaces 613 exposed by washing are spaced at a distance 619, and have a width 617 equal to separation distance 619. The remaining emulsion 604b acts as an optical mask to absorb stray rays that would interfere with stereo perception, and also to absorb incident radiation to prevent reflection from the screen. Due to the small radius of curvature of the lenslet surfaces 613, any reflection from point source ambient lighting is also greatly diffused.

FIG. 22 depicts a heated roller method of manufacturing of lens arrays. A sheet of 0.004 inch transparent plastic 701 is sandwiched on either side by molds 609 and 610 made the same as the molds described in conjunction with FIG. 16. Two smooth rollers 700a and 700b are heated to 325 degrees Fahrenheit with enough pressure applied to extrude lenslets from the molds 609 and 610. The resulting pre-assembly 702 is then cut to the desired lenslet array size. Mold substrates 600 are peeled off and the material is processed as described in conjunction with in FIG. 19. It will be further appreciated that a mold can be electroplated or plasma sprayed to form a metal mold for the particular lens array to be made.

FIG. 23 A-D illustrate an electrostatic method of forming lenslet arrays using a powder coating technology. Referring to FIG. 23 A, an assembly

comprising upper and lower substrates 900, 902, respectively, a transparent conductive layer 901, and upper and lower conductive masks 903 and 905, respectively, is prepared. The conductive layer 901 is elevated to a positive electrical potential by power supply 906. Negatively charged powder particles 911, such as Ferro VP 188 or Valspar PTC 00004 are applied by powder guns 907 and 908 to the upper and lower surfaces of the assembly 910. FIG. 23b shows the assembly 910 of FIG. 23a in greater detail. Particles 911 are held in place by the positive charge on substrates 900 and 902. This charge is contoured by negative conductive masks 903 and 905 and positive conductive layer 901. The assembly is inserted into an oven 912 (FIG. 23a) and baked at a suitable temperature and for a suitable period of time until the powder melts and sticks together. The shape of the resulting surface 913 (FIG. 23c) in the upper substrate is dictated by the dielectric constant of the substrate 900, the strength of the field, the thickness of the substrate, and the surface tension of the molten powder which is a function of oven temperature. A baking temperature of 325°F for 25 minutes has proven satisfactory. The shape of the resulting surface 912 in the lower substrate 902 is also dictated by the above parameters, as well as by gravity. The particular properties of the materials selected for substrates 900 and 902, will influence the shapes of the surfaces 913 and 912 (FIG. 23d), and the materials chosen will be dictated by the desired radii of curvature for the particular application. However, it is preferred that surface 912 be of a smaller diameter and radius of curvature than surface 913 in order to optimize performance of the resulting lenslet array. It is preferable to make surface 913 have a radius of curvature 13 times that of surface 912.

It is to be understood that assembly 910 could be made in two pieces and later bonded with a transparent resin or cement if lens shape requirements so dictate. FIG. 24 represents a variation of the electrostatic lens array method of manufacture. Substrate 900 with a conductive coating 901 has powder 911 electrostatically applied and its buildup controlled by the electric field gradient. A carrier 920 supports the substrate while baking occurs. Carrier 920 has a multiplicity of holes 922 arranged in an array having a diameter equal to that of the larger lenslet diameter. Substrate 900 sags into the holes 922 slightly forming the surface of the larger lenslets. The smaller lenslet size is controlled by the size of conductive mask 903, the electric field gradient, bake time and temperature, and the dielectric constant of the material used as substrate 900.

FIG. 25 represents a xerographic method of forming lenslet arrays on high temperature plastic sheeting 1006, such as transparency film or PTE polyethylene terepthallate sheeting commonly used as photographic film backing. Sheet feeder 1000 feeds sheet 1006 into a drum 1002 with an electrostatic pattern 1005 formed from a master or computer stored pattern and transferred to drum 1002 by laser or optics. A magnetic brush and feeder assembly 1003 applies standard black xerographic toner to drum 1002. The dark areas of pattern 1005 represent toner sticking to drum. The toner is then transferred to sheet 1006 to form an optical mask sheet. The applied mask is cured in a heater assembly 1007 and the sheet continues to drum 1009 having a pattern 1008. Powder (not shown) is applied by a magnetic brush assembly 1010 to drum 1009 and transferred to the partially processed sheet 1006. The sheet is routed back through oven 1007 and baked, creating an array of lenses on one side of the sheet 1006. Standard color xerography registration techniques are used to keep the pattern from drum 1009 centered on the pattern from drum 1002. Sheet 1006 then passes through sheet flipper 1010. A mask pattern changer changes the size of patterns 1005 and 1008 to meet previously described lens size ratios, and the sheet is processed on the opposite side. After passing through roller 1009 a second time, the sheet 1006 passes through a gate 1012 which directs the sheet to an exit processing station for trimming.

FIG. 26 illustrates another embodiment of the invention comprising an ionic electrically adjustable lenslet array 10. Structures 1102 and 1104 are parallel transparent sheets. Sheet 1104 contains a plurality of opaque seal rings 1106 which define a region 108 between sheets 1102 and 1104 in which a tungsten heater element 1110 and a halogen (e.g., iodine) are contained. Heater element 1110 forms a small loop and comes through sheet 1104 on feed through support assemblies 1105.

In operation, tungsten heating element 1110 is heated to form a tungsten halogen ion cloud 1112. Cloud 1112 refracts light rays passing through the enclosed region 1108 between sheets 1104 and 1102. A lens is formed by the varying density gradient of the tungsten halogen cloud in the vicinity of heating element 1110. By varying the heating element temperature, lens magnification is changed. Element 1110 can be heated by any suitable method, such as by resistance heating, eddy current heating, or electron bombardment. The lens effect becomes effective long before element 1103 becomes bright enough to see.

The distance between the heating element 1110 and the sheets 1102 and 1104 can be varied to move heater element 1110 within the enclosed region 1108 to change the shape of the lens from plano-convex to concave-concave. The shape of the element 1110 can also be changed to change the lens configuration. For example, element 1110 could be an electron heated disk or ring with the lens forming a cloud around its perimeter. A multiplicity of these ionic lenses forms a lens array. Micro electronic techniques could also be used to place heating element 1110 directly on either sheet 1102 or sheet 1104.

The foregoing description of preferred and alternative embodiments and methods of manufacture are illustrative examples of the essential teaching disclosed herein. Considerable variation in the parameters of the optical systems and methods disclosed here may be desirable or necessary for other media and image sources, depending upon the size of the adjacent picture elements to be separated, the distance to the viewer, and other factors. Furthermore, the lens assemblies as disclosed herein can be used in conjunction with vision augmentation devices such as contact lenses or eyeglasses to improve depth perception in a single eye or in both eyes. The scope of the present invention as defined in the appended claims is intended to cover all such modifications from the embodiments disclosed herein.

Furthermore, as noted, the conversion means lens assembly is adaptable to a variety of image producing sources, for example, printed photographs, and computer monitors, besides television sets. Accordingly, the scope of the present invention is intended to cover all such uses of the optical systems disclosed herein.

WHAT IS CLAIMED IS:

1. An apparatus for viewing a two-dimensional image, said two-dimensional image composed of a multiplicity of adjacent image elements generated from a single view and defining an object plane, comprising:

an optical system means to be placed adjacent said object plane for separating said adjacent image elements for independent viewing by the right and left eyes.

2. The apparatus of Claim 1, wherein said optical system comprises a two-dimensional array of lens assemblies.

3. The apparatus of Claim 2, wherein each of said lens assemblies comprises an object lens and an image lens, said object lens facing said object plane and said image lens facing the viewer.

4. The apparatus of Claim 3, wherein said lens assemblies further comprises a semi-rigid transparent layer disposed between said object lens and said image lens.

5. The apparatus of Claim 3, wherein the radii of curvature of said object lens and said image lens are chosen to minimize tangential coma and spherical aberration in separating adjacent image elements.

6. The apparatus as claimed in one of Claims 1-5, wherein said two-dimensional image is produced on the screen of a cathode ray tube.

7. The apparatus as claimed in one of Claims 1-5, wherein said two-dimensional image is a printed image composed of individual image elements.

8. The apparatus as claimed in one of Claims 1-5, wherein said two-dimensional image is a photographic image.

9. The apparatus as claimed in Claim 1, wherein said optical system comprises a first two-dimensional array of lens assemblies and a second two-dimensional array of lens assemblies, said first and second arrays overlapping each other and separated from each other by a predetermined distance.

10. The apparatus as claimed in Claim 9, wherein each of said lens assemblies of said first array comprise a double concave lens, and each of said lens assemblies of said second array comprise a convex lens.

11. The apparatus as claimed in Claim 1, wherein said optical system means comprises an electronically adjustable ionic lens system.

12. In combination with a film pack which includes a photosensitive medium for recording an image, an optical system comprising a two-dimensional array of lens assemblies placed adjacent said photosensitive medium within said film pack, and a removable normalizing layer making intimate contact with said two-dimensional array of lens assemblies.

13. The combination as claimed in Claim 12, wherein said lens assemblies comprise an objective lens and an image lens.

14. The combination as claimed in Claim 13, wherein said lens assemblies further comprise a semi-rigid transparent layer disposed between said object lens and said image lens.

15. The apparatus as claimed in Claim 4, wherein the diameter of said object lens is greater than the diameter of said image lens.

16. The apparatus as claimed in Claim 15, wherein the diameter of said object lens is at least twice the diameter of said image lens.

17. The apparatus as claimed in Claim 15, wherein said lens assemblies further comprise a light absorbing buffer ring surrounding said image lens.

18. An apparatus for display of a projected image generated from a single view, said projected image composed of a multiplicity of adjacent image elements, comprising:

an optical system means for separating said adjacent image elements, said optical system means comprising a two-dimensional array of lens assemblies and a specularly mirrored surface on one side of said array reflecting said projected image, said array separating adjacent image elements of said reflected image for independent viewing by the right and left eyes.

19. The apparatus as claimed in Claim 18, wherein said projected image is projected from film.

20. The apparatus as claimed in Claim 18, wherein said lens assemblies comprise an object lens and an image lens, said specularly mirrored surface being applied to said object lens.

21. A method of manufacturing a device for viewing a two-dimensional image, comprising the steps of:

(a) placing a layer of UV curable optically clear plastic between upper and lower plastic sheets to form a sandwich;

(b) placing said sandwich between upper and lower molds having an array of concave surfaces;

(c) applying pressure to said molds and to said sandwich so as to squeeze said sandwich into said molds; and

(d) curing said sandwich in the presence of UV light.

22. The method as claimed in Claim 21, wherein said pressure is vacuum pressure.

23. The method as claimed in Claim 21, wherein said upper and lower molds include mold surfaces, said mold surfaces being photographically created on said upper and lower molds.

24. The method as claimed in Claim 21, wherein said upper and lower molds include mold surfaces, and a portion of said upper and lower mold surfaces remain on said sandwich after curing so as to form a light absorbing buffer ring mask.

25. A method of manufacturing a device for viewing a two-dimensional image, comprising the steps of:

(a) forming a sandwich comprising upper and lower transparent plastic sheets; and

(b) feeding said sandwich through upper and lower heated rollers having a die surface to thereby impress said upper and lower transparent plastic sheets with a two-dimensional array of lens assemblies.

26. The method of Claim 22, wherein said sandwich further comprises a middle layer of semi-rigid transparent material.

27. A method of manufacturing a device for viewing a two-dimensional image comprising the steps of:

applying laser light to a sheet of optically clear plastic material so as to vaporize a portion of said sheet to thereby form a plurality of convex lens surfaces on both sides of said sheet.

28. The method as claimed in Claim 27, wherein said sheet has a center layer of transparent semi-rigid material in which a portion of said material is vaporized by said laser light.

29. The method is claimed in Claim 27 or Claim 28, wherein said laser light is in the form of a beam and said sheet is movable relative to said beam, and wherein said beam is applied to closely adjacent regions of said sheet to thereby create an array of said convex lens surfaces on both sides of said sheet.

30. The method as claimed in Claim 29, wherein said beam is stationary and said sheet is installed on a table movable relative to said beam according to a set of previously determined commands.

31. A method of manufacturing a device for viewing a two-dimensional image comprising the steps of:

preparing a sandwich construction of upper and lower molds having concave surfaces and a layer of optically clear material interposed between said upper and lower molds;

pressing said layer of optically clear material into said concave surfaces; and;

removing at least a portion of said upper and lower molds, the remainder of said upper and lower molds remaining on said layer of optically clear material to thereby form a light absorbing buffer ring mask.

32. The method as claimed in Claim 28, wherein at least one of said upper and lower molds is photographically produced.

33. A method of manufacturing a device for reviewing a two-dimensional image, comprising the steps of:

(a) forming an assembly comprising upper and lower substrates, a first mask applied to said upper substrate and a second mask applied to said lower substrate, and a transparent conductive material between said upper and lower substrates;

(b) elevating said conductive material to an electrical potential relative to said first and second masks;

(c) applying a charged powder to said upper and lower masks; and

(d) heating said assembly for sufficient time and at a sufficient temperature to cause said substrates to develop upper and lower lens surfaces in regions provided in said first and second masks.

34. The method as claimed in Claim 33, wherein said lower lens surfaces are of a lesser diameter and smaller radius of curvature than said upper lens surfaces.

35. A method of manufacturing a device for viewing a two-dimensional image comprising the steps of:

(a) applying a xerographic toner to a first side of a plastic sheet in a mask pattern;

(b) curing said sheet in a heater;

(c) applying a powder to said sheet in registering with said toner;

(d) baking said sheet to thereby forming an array of lenses on said sheet.

36. The method as claimed in Claim 35, wherein said sheet has a second side and said steps (a), (b), (c) and (d) are repeated to said second side.

37. The apparatus of Claim 1, wherein said optical system means comprises:

(a) a front transparent sheet;

(b) a rear transparent sheet; and

(c) means for generating a multiplicity of ion clouds between said front and rear ion sheets to thereby evaluate a multiplicity of lenses between said front and rear sheets.

38. The apparatus of Claim 37, wherein said means for generating comprises at least one heater element, a halogen, and means for containing said halogen in a multiplicity of volumes, said halogen forming a cloud when heated by said heater element to thereby emulate a lens.

39. An apparatus for enhancing vision comprising, in combination, a vision augmentation device; and a two dimensional array of lens assemblies placed adjacent to said vision augmentation device.

40. The apparatus as claimed in Claim 39, wherein said vision augmentation device is a contact lens.

41. The apparatus as claimed in Claim 39, wherein said vision augmentation device is a spectacle.

42. The apparatus as claimed in Claim 39, wherein said vision augmentation device is a coherent fiber optic cable having a first end and second end, and wherein said two dimensional array of lens assemblies comprises a first two dimensional array of object lenses placed adjacent to said first end of said fiber optic cable, and a second two dimensional array of image lenses placed adjacent to said second end of said fiber optic cable.

Fig 1

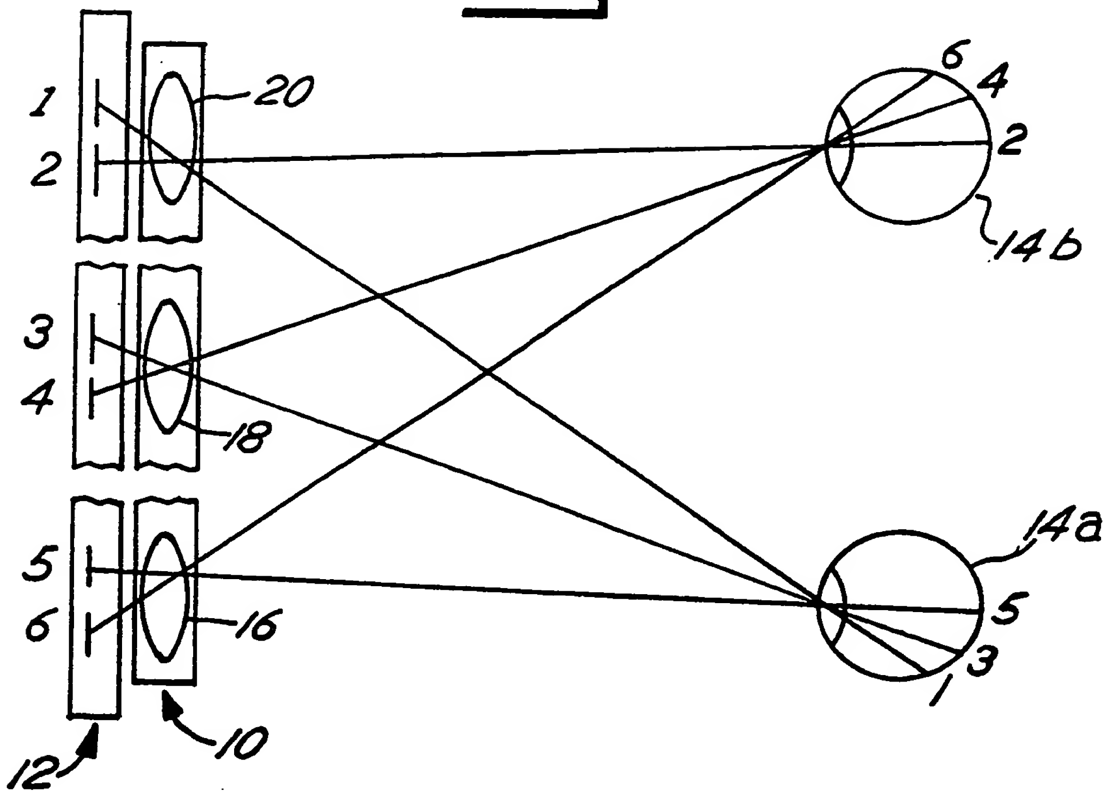


Fig. 2

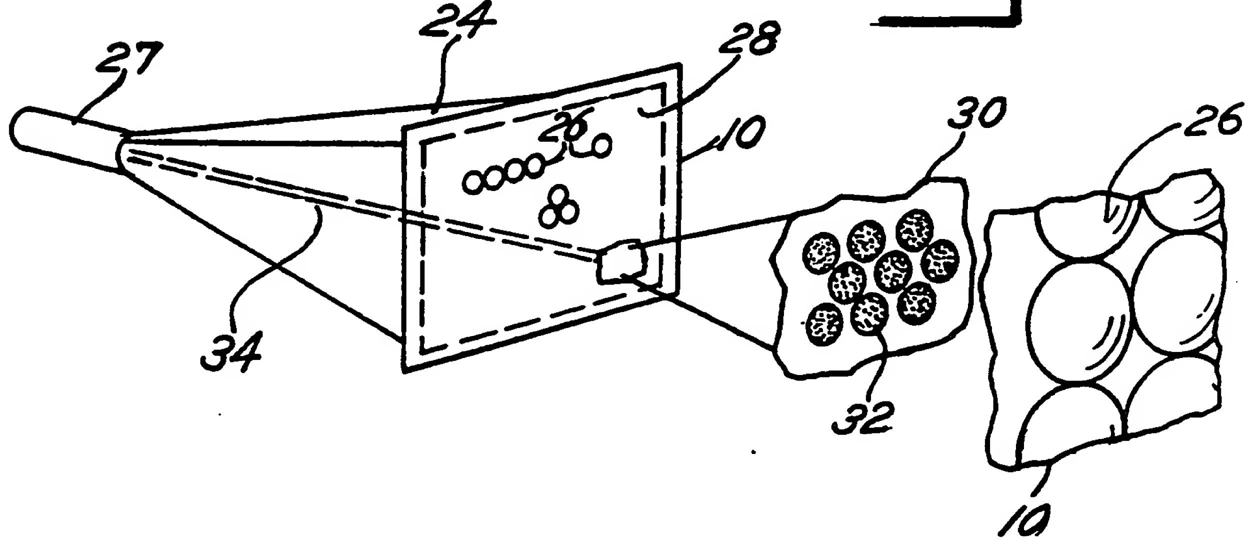
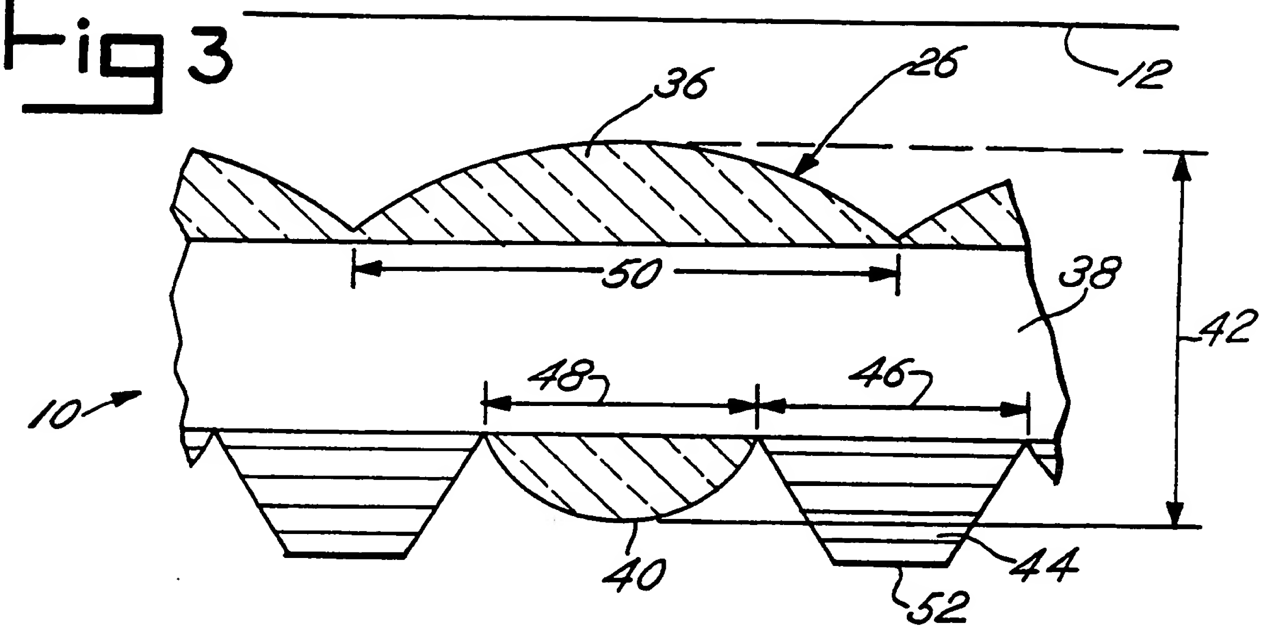


Fig 3



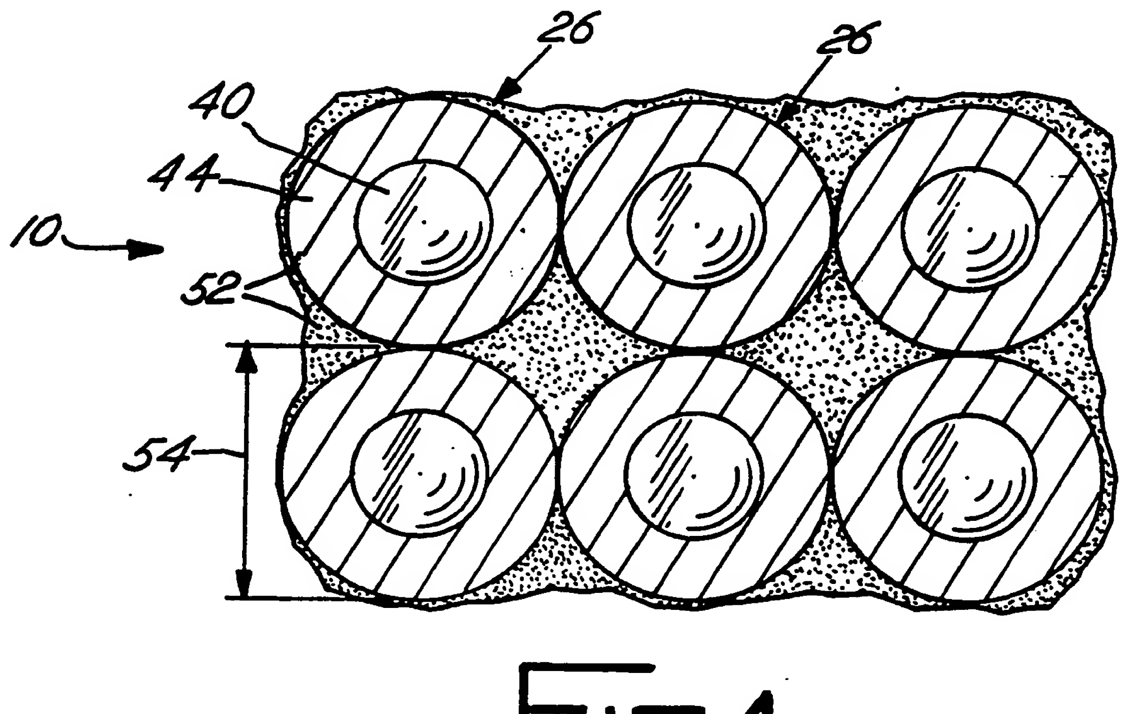
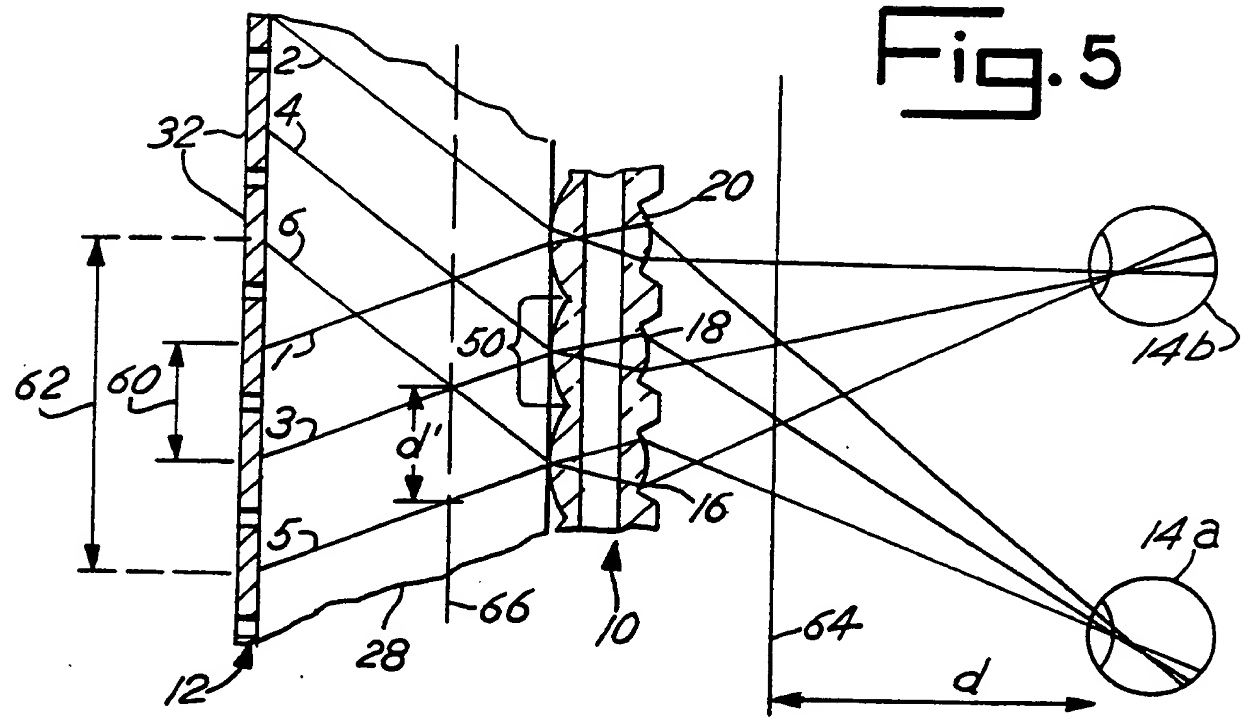


Fig.4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5
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50
20
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16
d'
66
28
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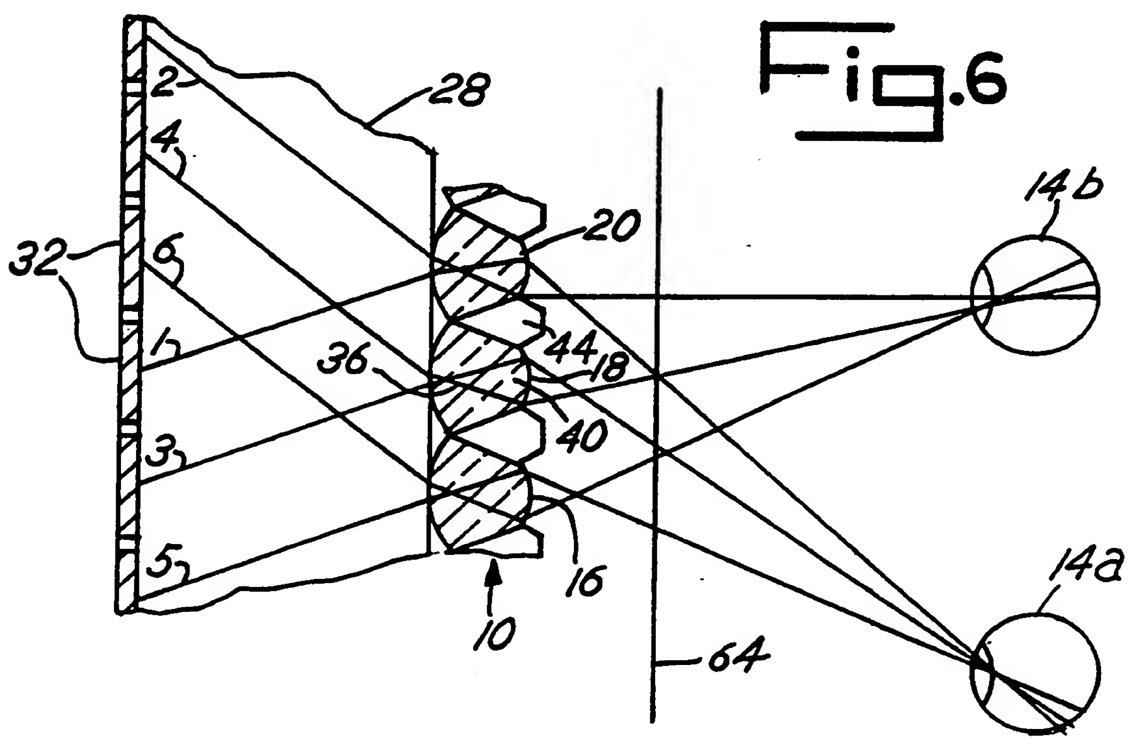
12
64
d
14b
14a

Fig. 5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14a

Fig. 6

Fig 7

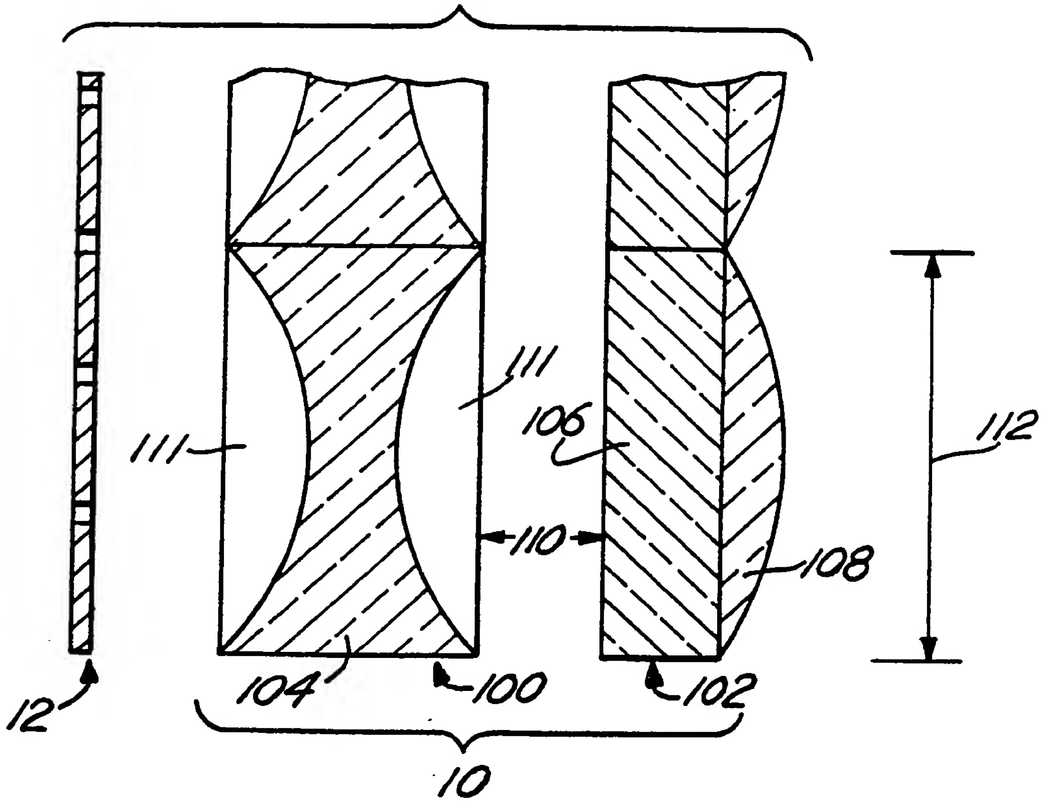
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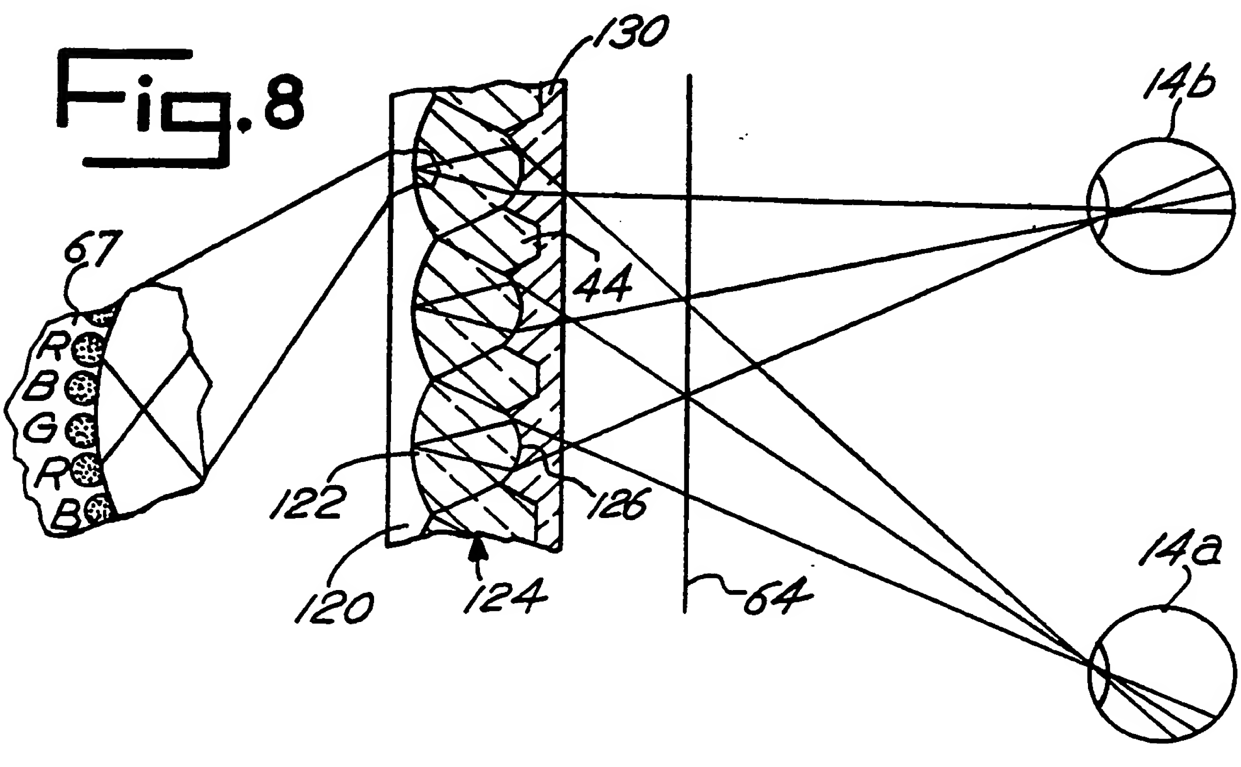
Fig.8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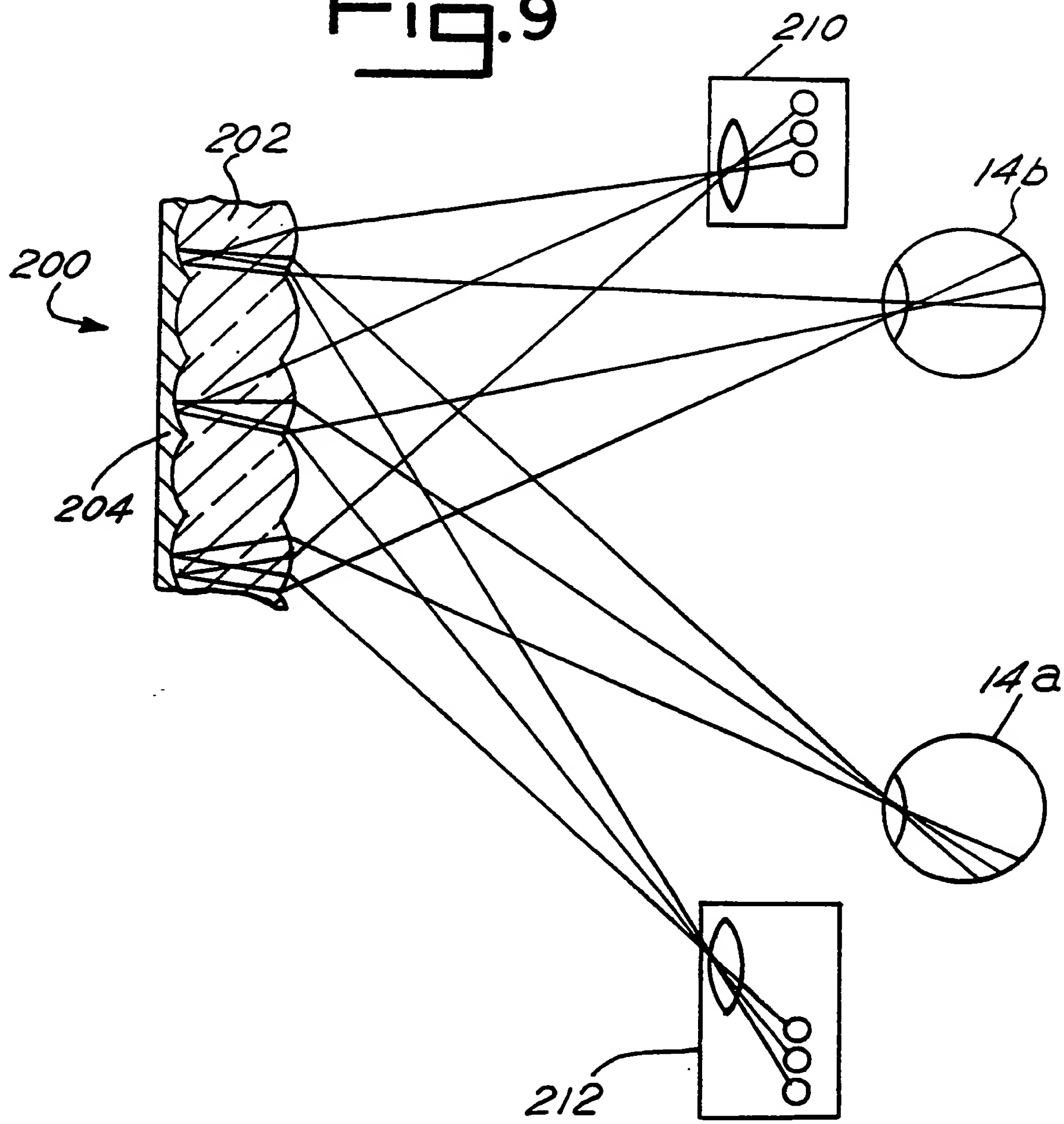
14a

Fig.9



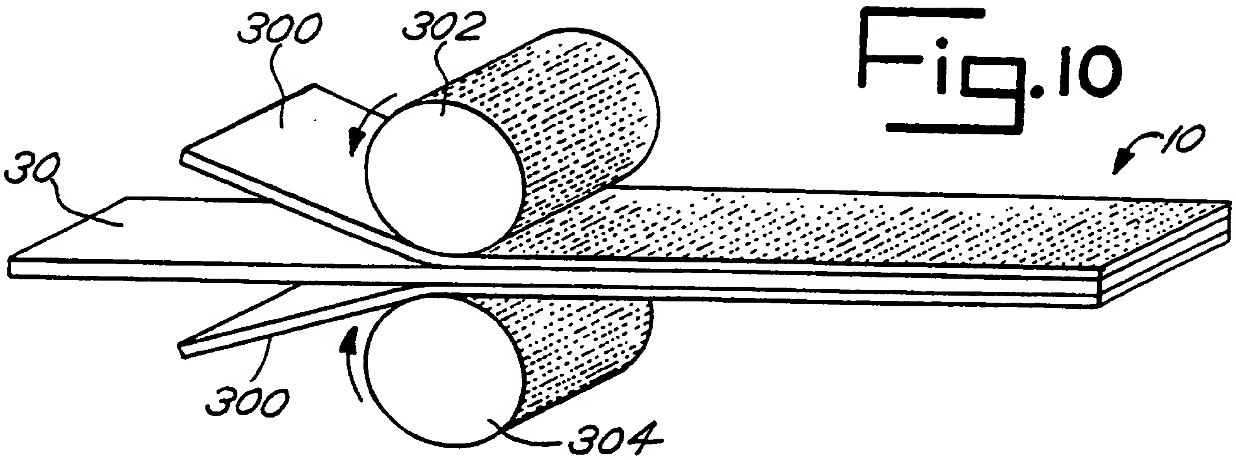


Fig.10

Fig.11

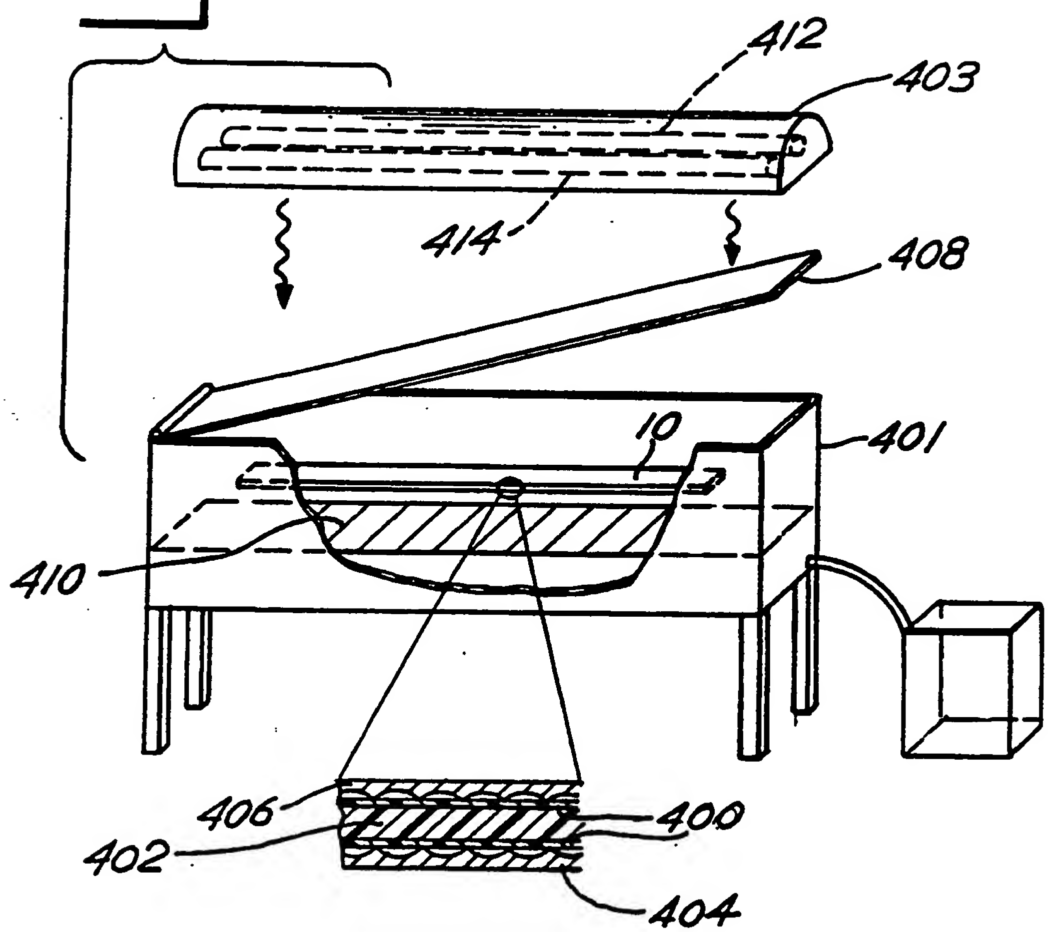


Fig.12A

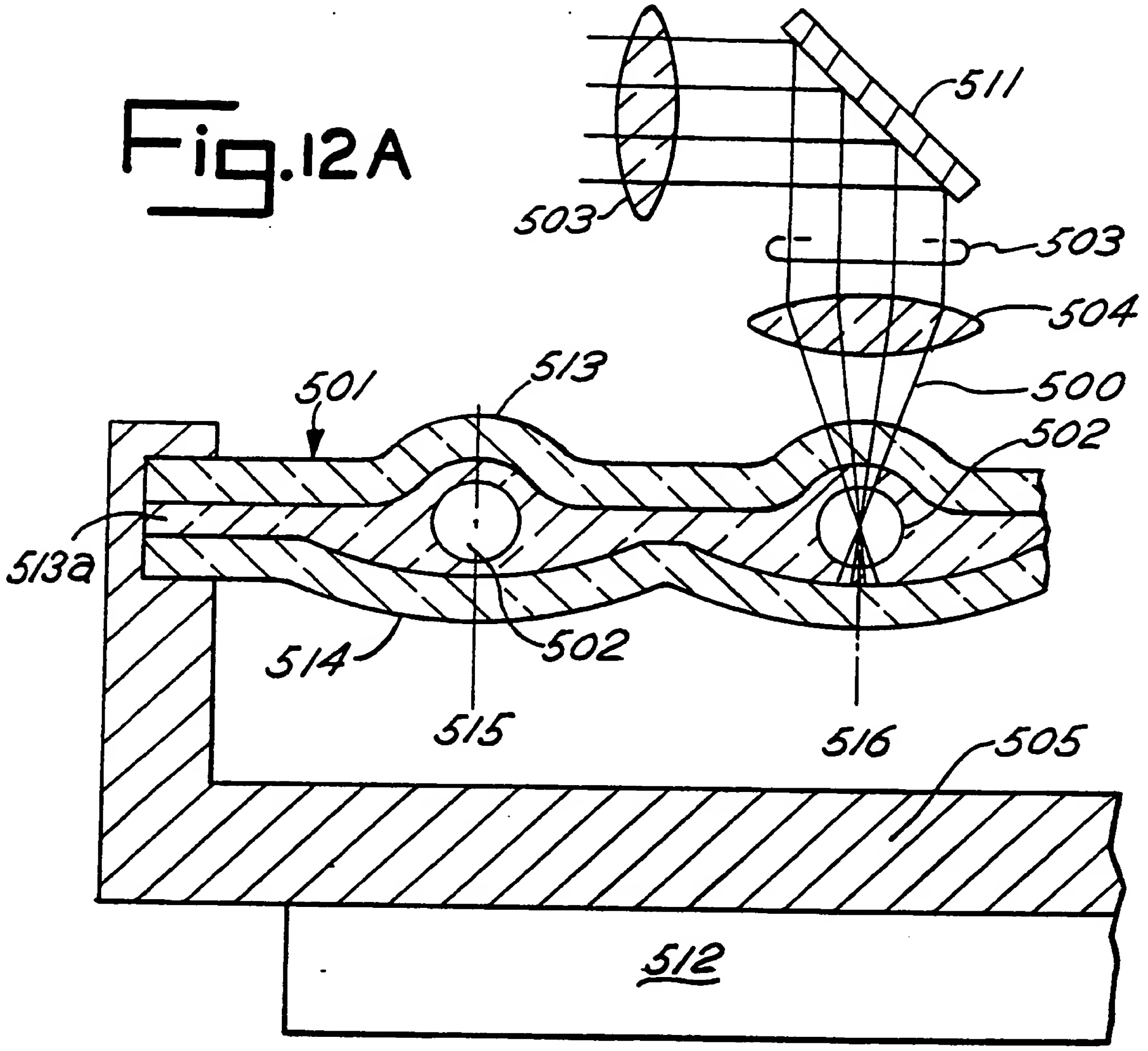


Fig.12B

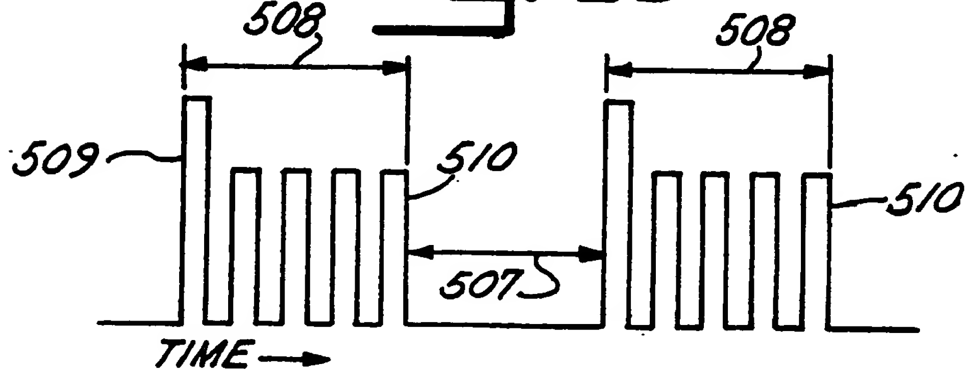


Fig 12C

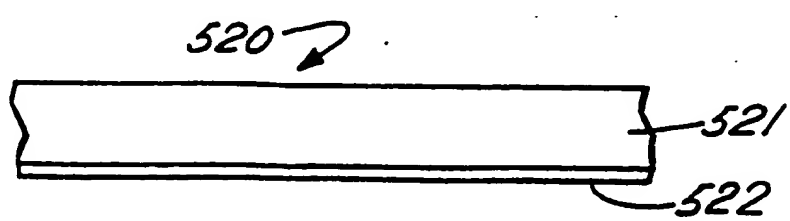


Fig. 13

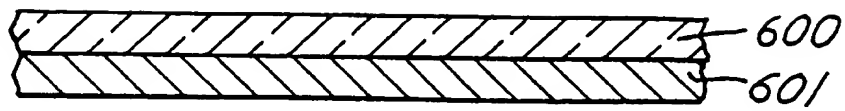


Fig. 14

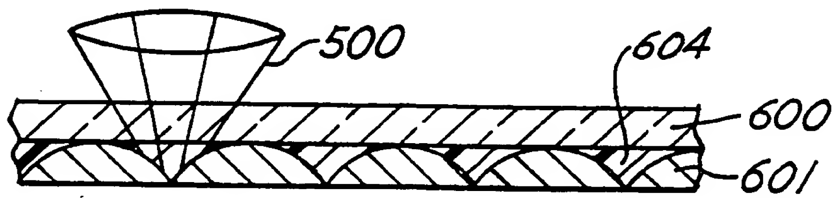


Fig. 15

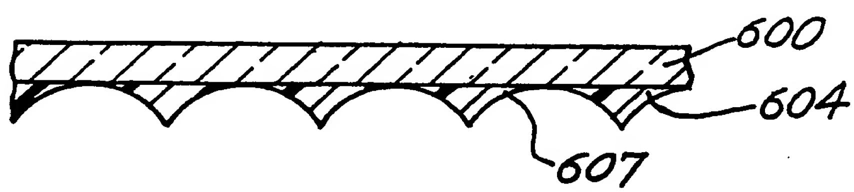


Fig. 17

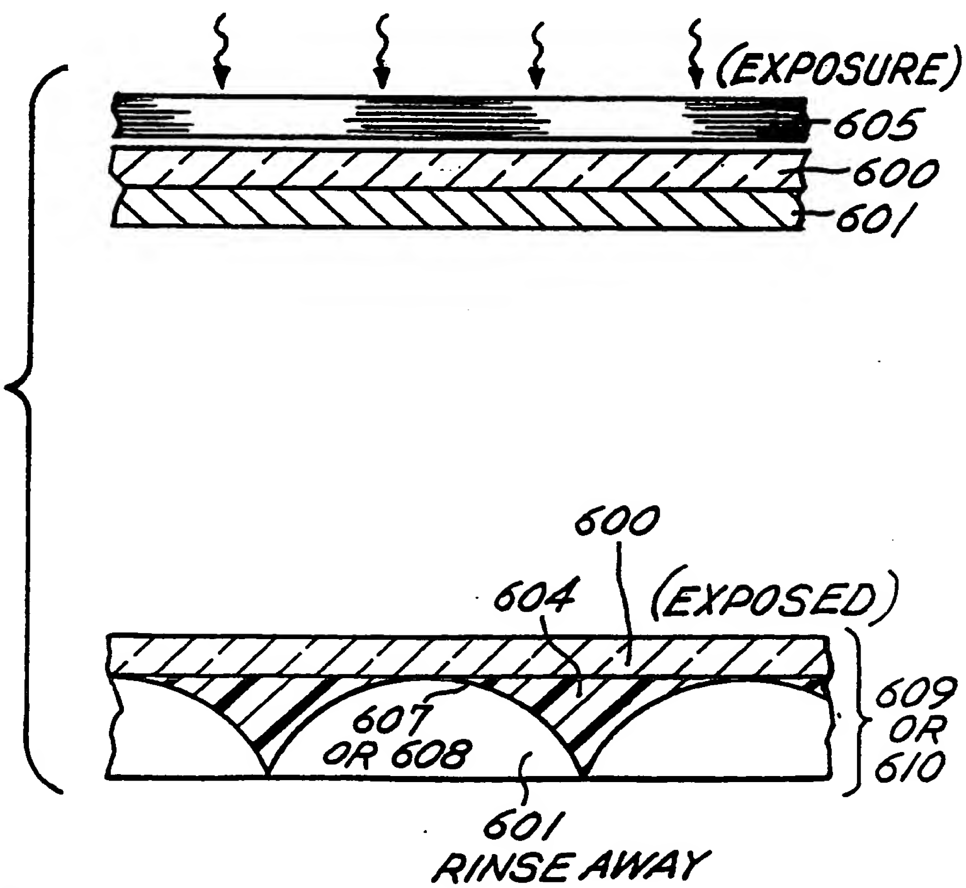


Fig. 16

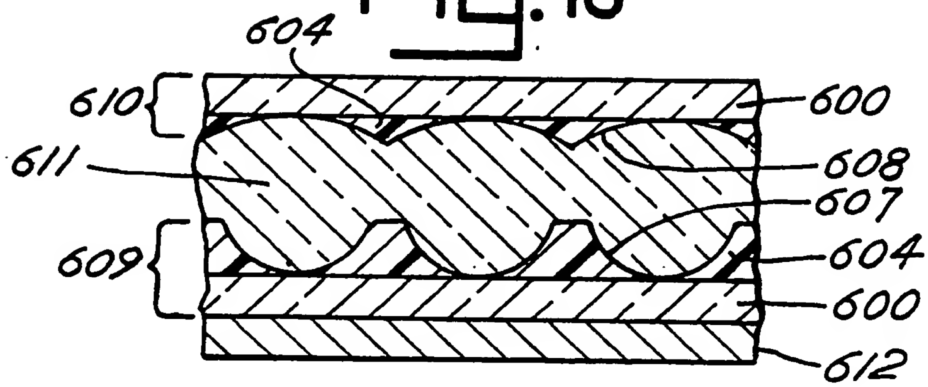


Fig. 18

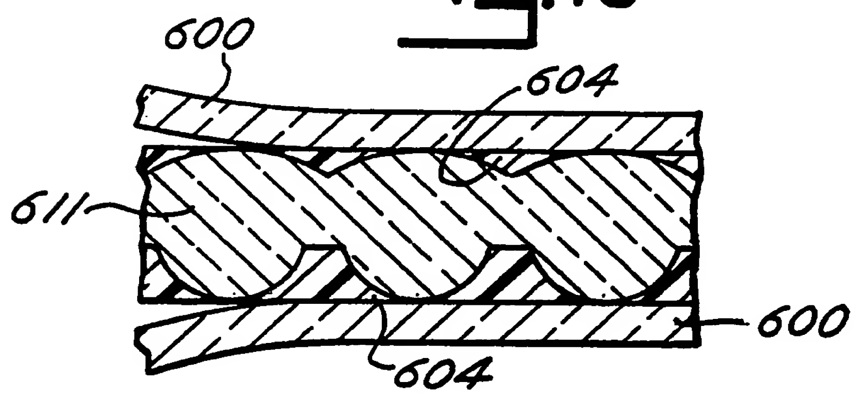
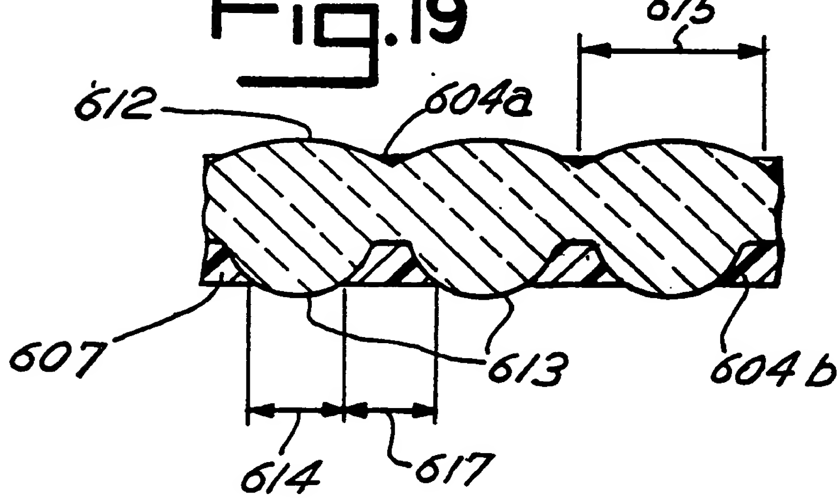


Fig. 19



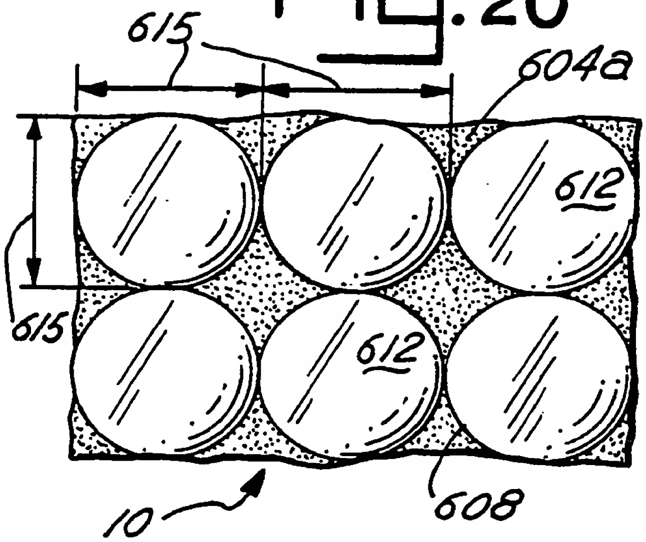


Fig.20

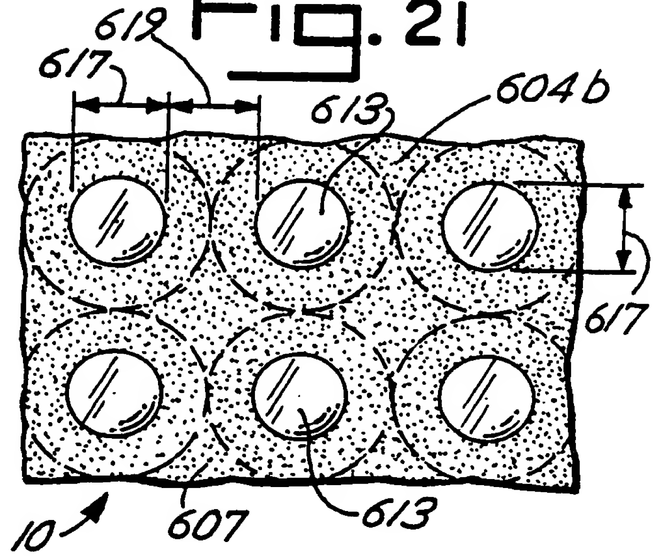


Fig.21

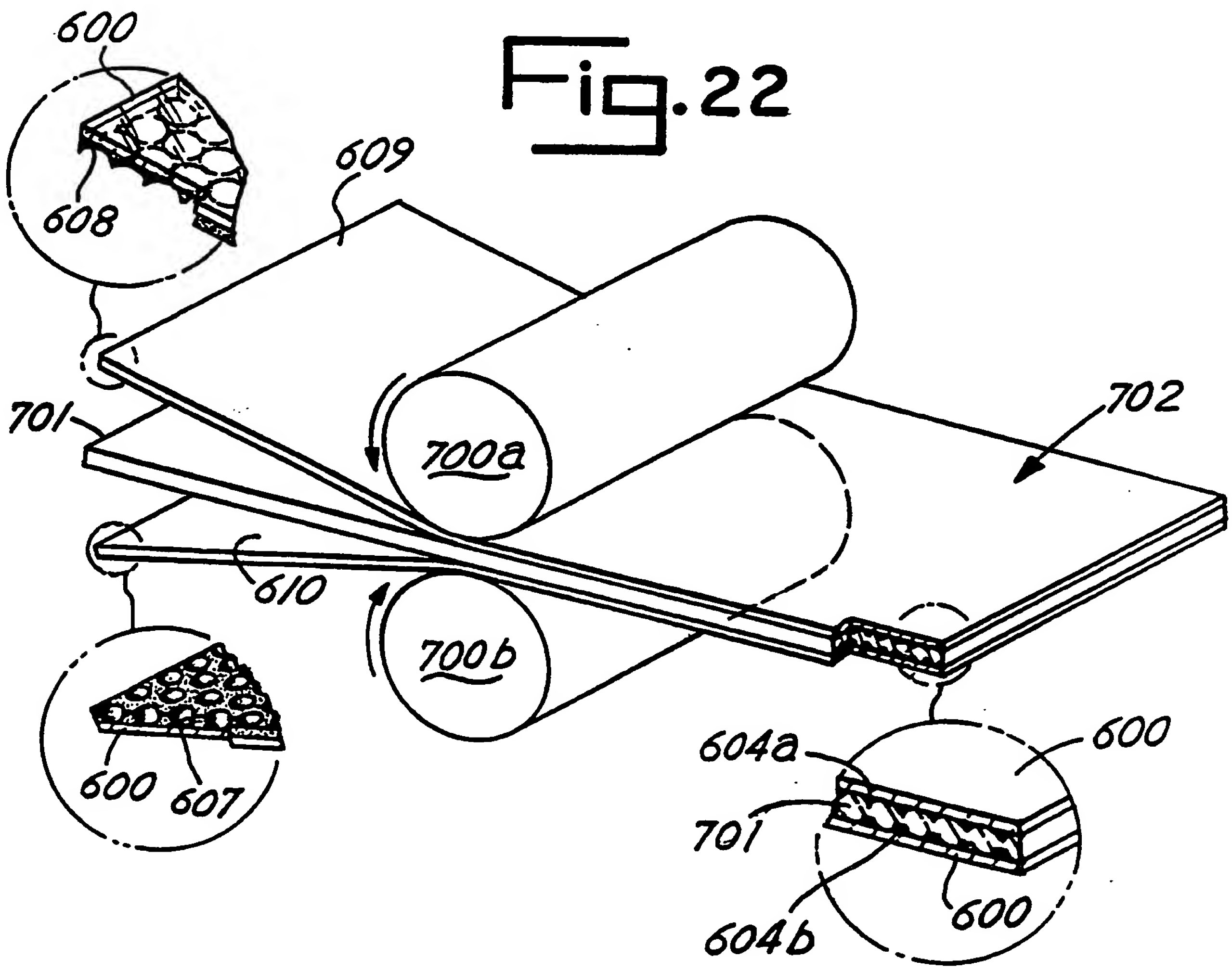


Fig.22

Fig. 23A

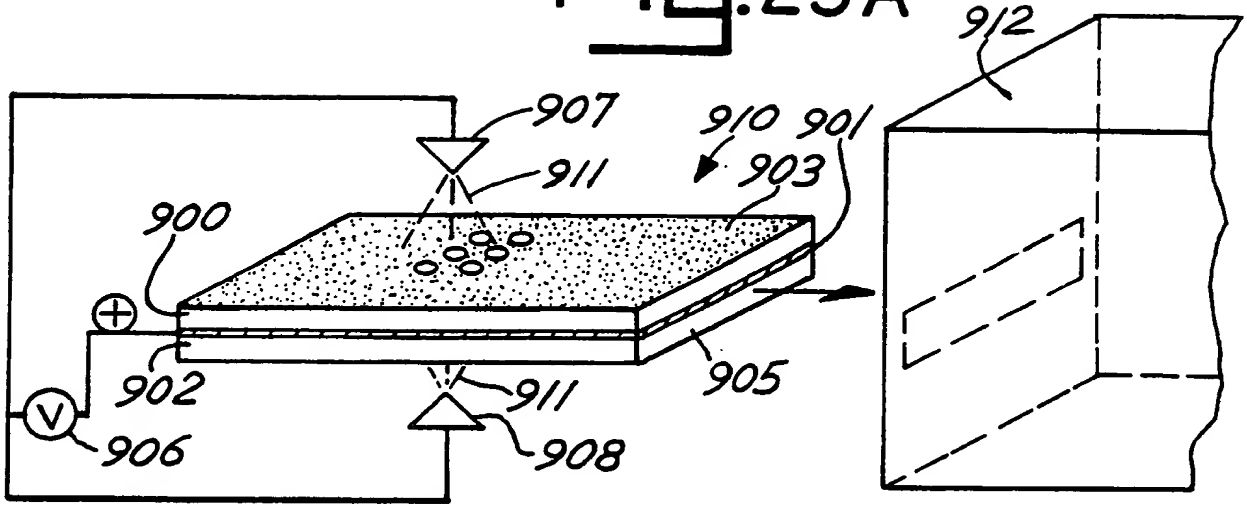


Fig. 23B

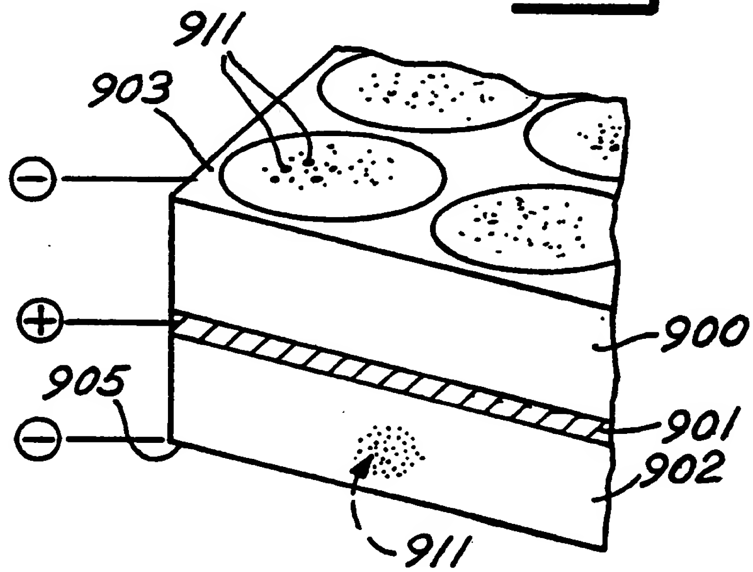


Fig. 23C

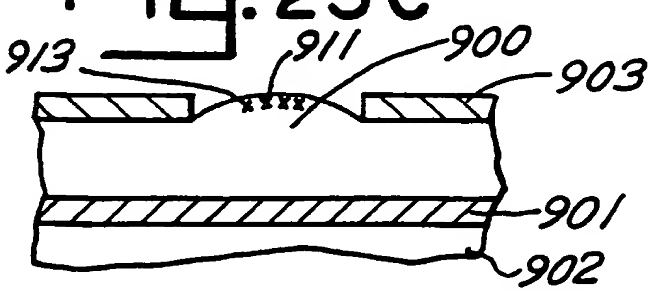


Fig. 23D

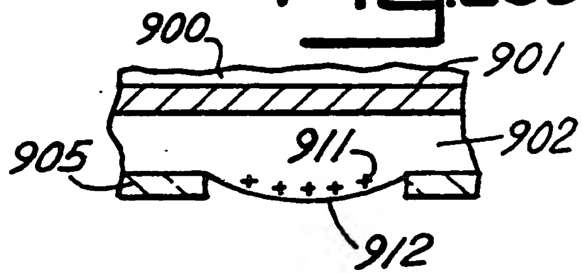


Fig.24

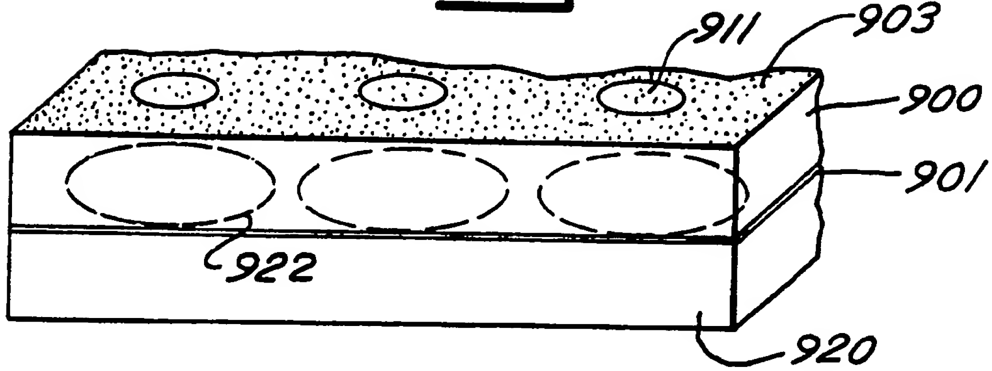
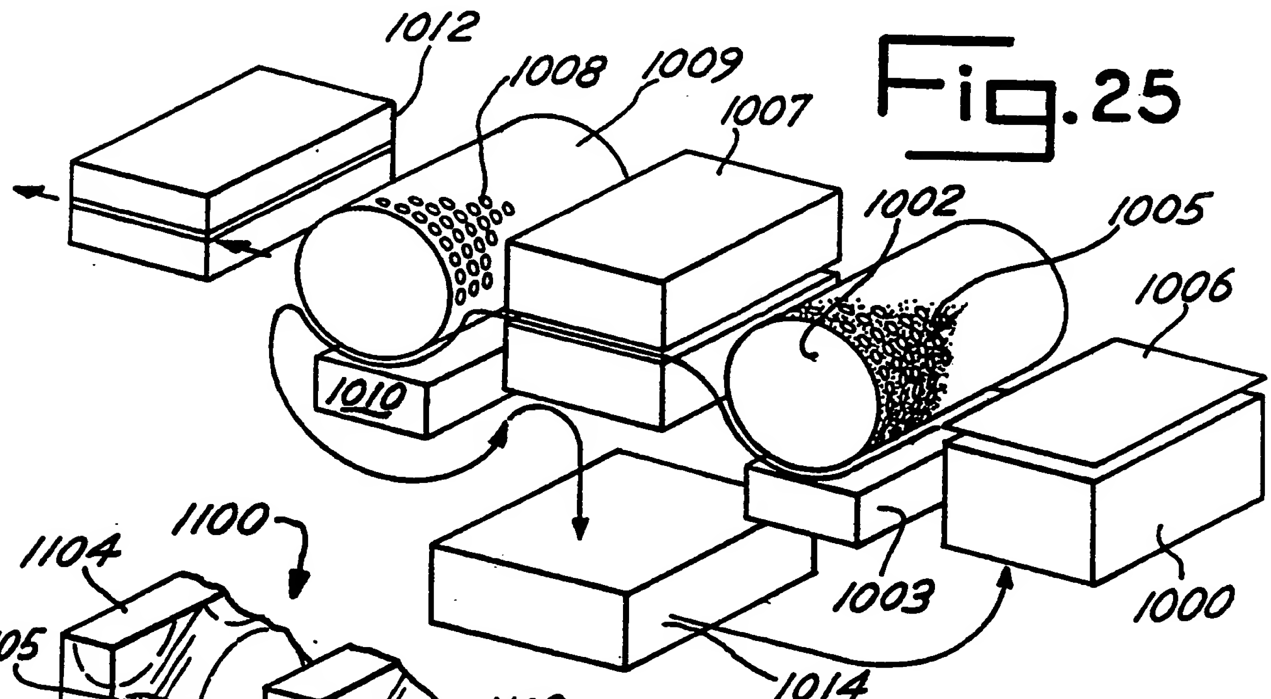


Fig.25



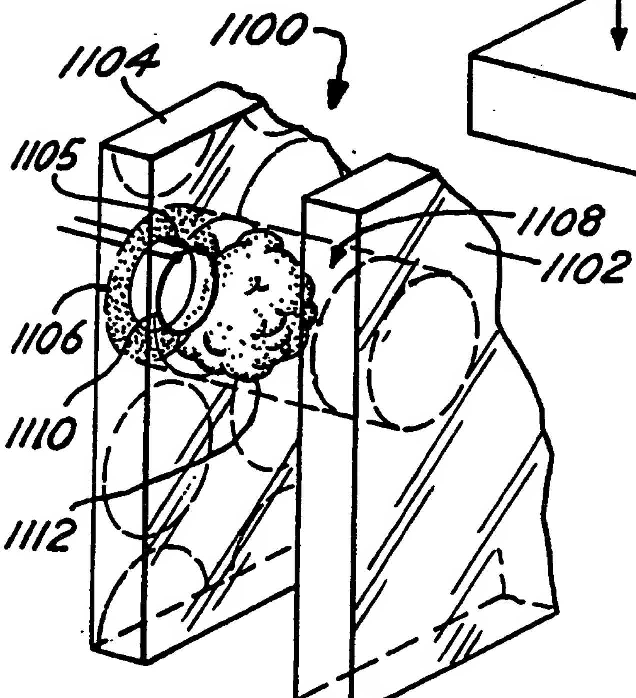


Fig 26

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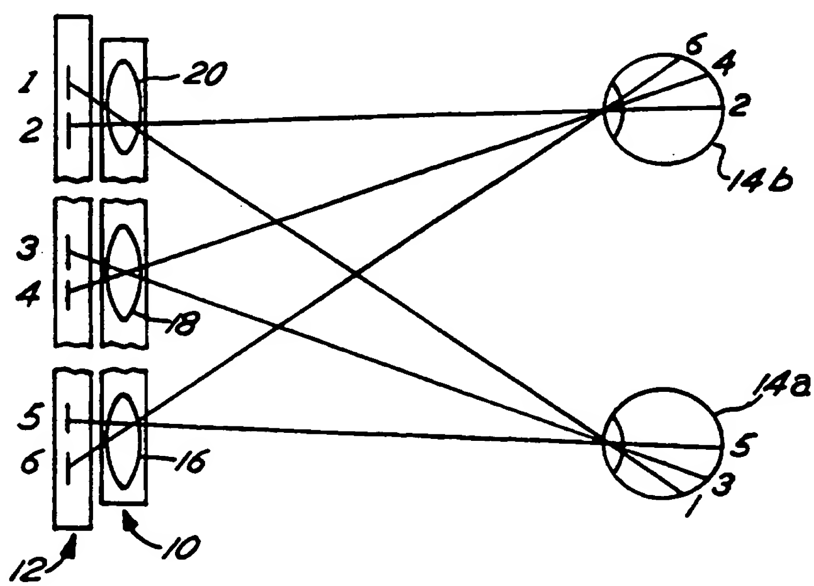

(57) Abstract

An apparatus for three-dimensional display of a two-dimensi nal image generated from a single view such as that produced on a television screen or a ph t graph. The apparatus comprises a two-dimensional array of lens assemblies which are placed adjacent to the plane f the two-dimensional image. The lens assemblies comprise, in the preferred embodiment, an object lens, an image lens, and a semi-rigid transparent layer between the lenses. The apparatus can be modified to provide three-dimensional viewing of a projected image such as that produced by a slide or movie project r by adding a specularly mirrored surface to the object lens and placing the apparatus at distance where the screen w uld normally be. Several methods of manufacturing the apparatus are discl sed.

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DK	Denmark	MG	Madagascar		
ES	Spain				

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 91/08589

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl.5 G 02 B 27/22 G 03 B 35/24 H 04 N 13/04

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
Int.Cl.5	G 02 B G 03 B H 04 N

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category °	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No.[13]
X	GB,A,1382592 (WILLIAM FREDERICK KYRYLUK) 5 February 1975 see the whole document	1,2,6
A		3-5,7-10,15-17

X	DE,A,2110623 (AGENCE NATIONALE DE VALORISATION DE LA RECHERCHE (ANVAR)) 23 September 1971 see the whole document	1,2
A		3-10,15-20
	--- -/-	

° Special categories of cited documents : [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
23-03-1992	13. 08. 92
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	J. CARLERUD

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category °	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
X	US,A,3689346 (W.P. ROWLAND) 5 September 1972 see column 5, line 16 - column 6, line 26; figures 1-7 ---	21,25
X	US,A,4294782 (GUY M. FROEHLIG) 13 October 1981 see column 2, line 64 - column 5, line 14; figure 1 ---	21,25
A	US,A,4486363 (ROBERT M. PRICONE ET AL) 4 December 1984 see abstract; figure 4 ---	21,25
A	EP,A,0262955 (BASS, MARTIN LAWRENCE) 6 April 1988 see column 2, line 61 - column 5, line 14 -----	1-10,15-17

INTERNATIONAL SEARCH REPORT

national application No.
PCT/US91/08589

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. Claims 1-20, 21-26, 31-32; 2. Claims 27-30
3. Claims 33,34; 4. Claims 35,36;
5. Claims 37,38; 6. Claims 39-42

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searches without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-20, 21-26, 31-32

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. US 9108589 SA 54454

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 22/07/92
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
GB-A- 1382592	05-02-75	CA-A- 962868	18-02-75
DE-A- 2110623	23-09-71	FR-A- 2094205	04-02-72
		US-A- 3712727	23-01-73
US-A- 3689346	05-09-72	None	
US-A- 4294782	13-10-81	None	
US-A- 4486363	04-12-84	DE-A,C 3332461	05-04-84
		GB-A,B 2127344	11-04-84
		JP-B- 3043051	01-07-91
		JP-A- 59140021	11-08-84
		US-A- 4601861	22-07-86
EP-A- 0262955	06-04-88	AU-A- 7923387	14-04-88
		GB-A,B 2196166	20-04-88
		JP-A- 63090289	21-04-88
		US-A- 4959641	25-09-90

EP FORM P0479

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82